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Research of Absorbing Properties of Lubricating Layers and Development of Plate Elastomeric Shock-Absorbers

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Abstract

The results of the evaluation of absorbing properties of the plate systems containing a layer of lubricant fluid between the contacting surfaces, dependences of absorptive capacity on the physical properties (adhesion, viscosity, etc.), load, temperature and other operational factors are presented in the article. The impact on the absorptive capacity of a number of lubricants and other fluids is experimentally estimated.
The design of the plate elastomeric shock-absorbers is developed on the basis of the received results. Their damping characteristics are estimated.

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Keywords: damping; surface friction; absorptive capacity; shock-absorber; adhesion; viscosity; lubricating layer.

1. Features friction and contact

The mechanical interaction of surfaces of friction units is a complex multifactor process of a dissipative type, in which the dominant is dynamics of formation of contact stresses [1 - 5].

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Nomenclature

P	Pressure
P_0	Pressure in the state of thermodynamic equilibrium
τ	Relaxation time
ρ	Density
ω	Cyclic frequency
C_0	Speed of sound in the medium in a state of thermodynamic equilibrium
C	true value of speed of sound
V	Amount
μ'	bulk viscosity
α	coefficient of the sound absorption
ω	circular frequency
c	speed of sound
ρ	density of the fluid
η_0’	statical shear viscosity
η_0”	bulk viscosity
τ_1	times of relaxation of the shear viscosity
τ_2	times of relaxation of bulk viscosity

In case of adding the lubricating fluid in the joint of contacting surfaces, the lubricating layer not only provides the reduction of friction (which is transferred into the fluid), but also performs the role of an intensively damping element, because the joint (between the contacting surfaces) is composed of 3 elements (2 surfaces and a lubricating layer). As a barrier zone for passing the dynamic pulses, the lubricating layer diffuses the dynamic energy more intensively than the sum of absorbing characteristics (of the decrement of oscillations) of the material of parts and lubricant [5-7].

If we consider the process that occurs in the joint as the adiabatic compression-expansion of a lubricating layer (described by the harmonic law $P=e^{iwt}$), then, the difference between the true value of pressure and the pressure in the state of thermodynamic equilibrium, is equal to the ratio [2, 8]

$$P - P_0 = \frac{\tau\rho}{1+\omega^2\tau^2}\left(C_0 - C\right)\mathrm{div}\overline{V}, \tag{1}$$

Also, it can be obtained from the generalized Newton's law:

$$P - P_0 = \mu' \,\mathrm{div}\overline{V} \tag{2}$$

$$\mu' = \frac{\tau\rho}{1+\omega^2\tau^2}\left(C_0 - C\right) \tag{3}$$

2. Accounting basic patterns

According to the research of water-glycerin liquid PGV in the Scientific Research Institute of Physics, St. Petersburg University, the bulk viscosity at high frequencies is small. At low cyclic frequencies it seeks to its static limit (Fig. 1, curve 1), since the frequencies of dynamic loads are relatively small and are in the audible range. This is the bulk viscosity that can be considered estimated. But, when added to a liquid, for example, cyclohexanol (7% of the mass), the viscosity increases sharply (curve 2) and seeks to viscosity PGV (curve 1).

The research of the dissipative properties of various lubricants showed that the decrement of the damped oscillations is the highest in oils having the high bulk viscosity (Fig. 2, curve 1 - for PGV and 3 for AU with an additive). The decrement of the oil (AU) without additive (curve 2) is lower, and it is even lower than during dry friction (curve 4).

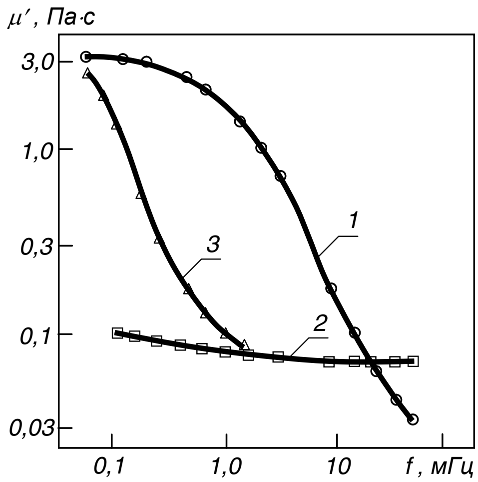


Fig. 1. Frequency dependence of the bulk viscosity (at 25 °C): 1 - liquid PGV, 2 - oil AU, 3 - oil AU with an additive (7% cyclohexanol).

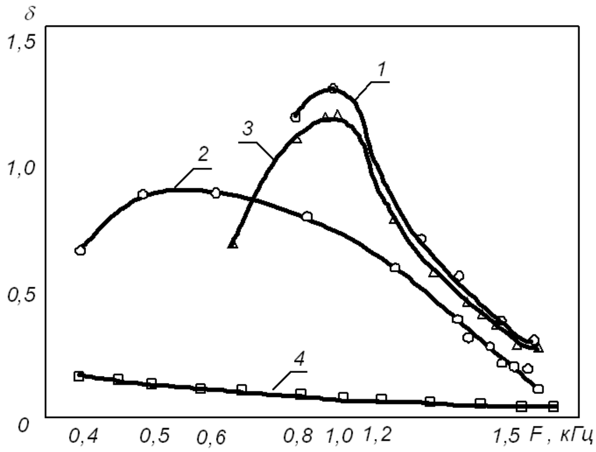


Fig. 2. The frequency dependence of the logarithmic decrement of oscillations δ: 1 - liquid PGV, 2 - oil AU, 3 - oil AU with an additive, 4 - without lubrication.

The illustration of the volumetric strain and scattering in the joints of the shock-absorber is illustrated in Fig. 3. The energy of the deformation, friction and pulsation of the pressure in the fluid layers between the plates also cause the transition of the mechanical friction work in the heat and its dissipation into the environment [9-11] .

According to the phenomenological relaxation theory of liquids [12] the coefficient of the sound absorption α for a single relaxation process, as for the shear viscosity and for the bulk viscosity is determined by the expression:

$$\alpha = \frac{\omega^2}{2\rho c^3}\left(\frac{4\eta_0'}{1+\omega^2\tau_1^{\,2}} + \frac{\eta_0''}{1+\omega^2\tau_2^{\,2}}\right) \tag{4}$$

The values η_0' and η_0" depend on the physical and chemical nature of liquids, components and the nature of their interaction. For liquids, such as cyclic hydrocarbons, the bulk viscosity is tens times higher than the shear viscosity. The relaxation times τ_1 and τ_2 are determined by their structure and by the nature of intermolecular interaction [9, 12] etc.

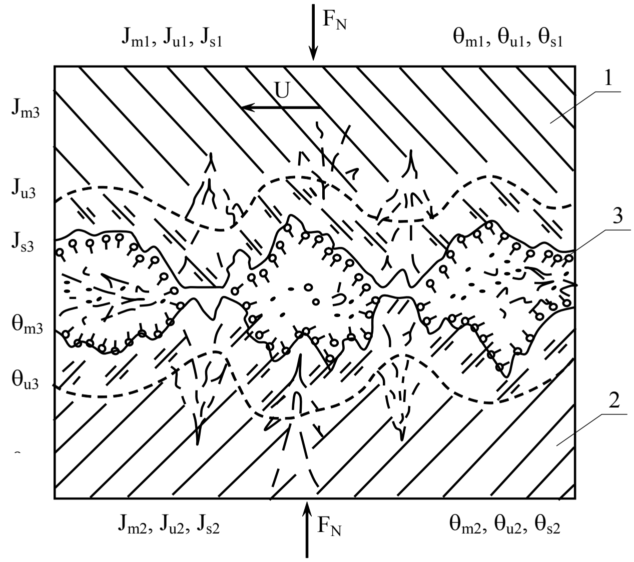
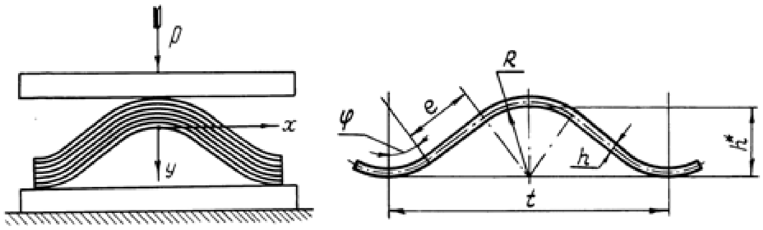


Fig. 3. Chart of processes occurring during dynamic loading the plates of shock-absorber: Jm_i and Θm_i – offset and moments, F_N – external load.

3. The device and the test plate absorbers

The polymethylsilicone liquids are selected as the most effective for the plate shock-absorbers. The optimal reliefs of surfaces of plates, for example, on the corrugated washers (Fig. 4 and 5) of the multilayer shock-absorbers (Fig.10) are also selected.



a b

Fig. 4. Scheme of loading the experimental packs of bands (a) and designation of parameters characterizing the profile of the corrugations (b).

a b

Fig. 5. The vibration isolator without a cover: a - with the silicone grease on the surfaces washers; b - one of the packages of quasi-closed rings of rope.

The test stand is shown in Fig. 6, the character of the damping of the shock oscillations is in Fig. 7. The test method is published in [12, 13] .

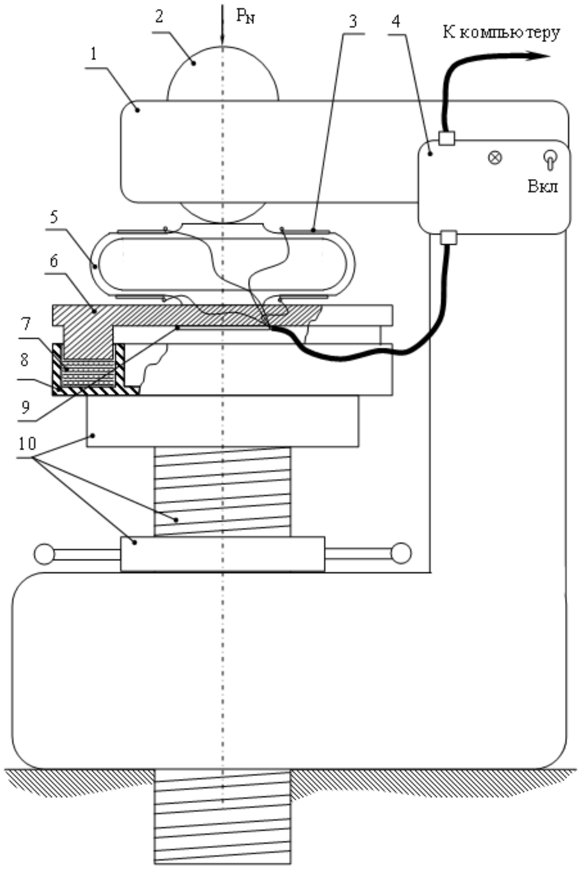


Fig. 6. Stand for vibration testing the plates of shock-absorbers: 1 - frame; 2 - spherical shock heel; 3 – sensors of static load; 4 - amp of signals from sensors and ADC; 5 - dynamometer; 6 - upper cover damper; 7 – corrugated plates;8 - lower cover of shock-absorber; 9 – vibration sensor; 10 - pressing mechanism.

The measurement of the load on the shock-absorber (Fig. 6) is performed using strain gauges - 3. The output of the strain gauges is attached to the block of the measuring amplifiers - 4.

The dynamic loading of the plate elastomeric shock-absorber installed on the test stand, is performed by a blow into the surface of heel - 2, transmitting the impact energy to the package of flat corrugated plates - 7, covered by a thin layer of damping fluid (Fig. 6).

Tests are conducted at specified load, and the force of impact is determined by the amplitude of the elastic displacement of the upper cover 6, relative to the bottom cover 8.

The electronic measuring system of the test stand (Fig. 6) includes: a strain gauge 3 (designed to measure the static load); a vibration sensor 9 mounted on the top cover 6 of the plate elastomeric shock-absorber; unit measuring amplifiers 4.

The output signal from the unit of measuring amplifiers 4 through the converter ADC-USB is transmitted for analysis and saving to the program (Adobe Audition) on the computer (Fig.7).

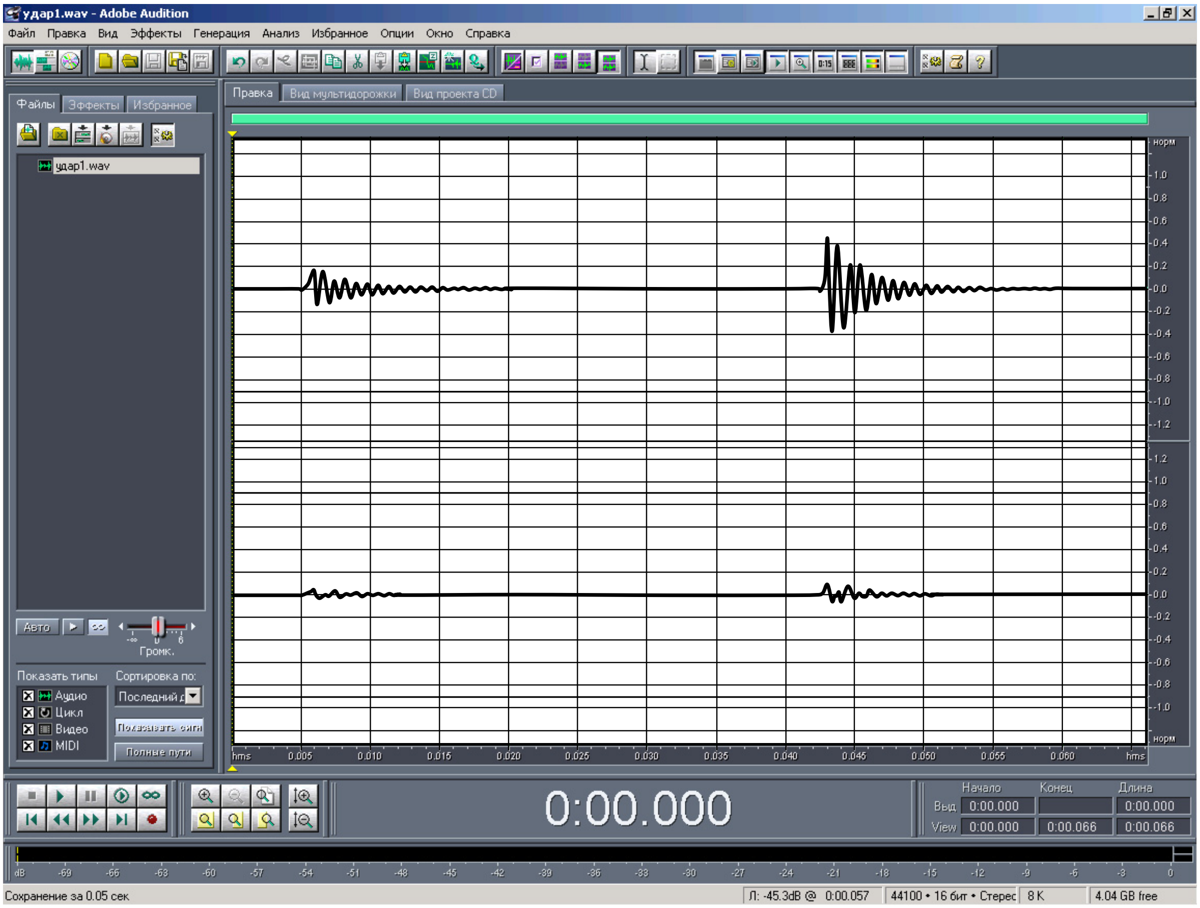


Fig. 7. The signals are recorded during the impact at the inlet (upper curve) and output (lower curve).

The main criterion for the selection of the damping fluid in the tests is the dependence of the logarithmic decrement of the oscillations from the force of the blow in a number of values of the static load, for example, 171 and 342 kg at negative (-10...-15 °C) and positive (+20 °C) temperatures.

The results of the tests are presented in Table 1 and in Fig. 8.

The Figures (Tables) show that the silicone fluids PMS60000 (charts 1 - 4) and PMS500 (charts 9 - 12), and their combination PMS60000 + PMS500 (see charts 17 - 20) have a high value of damping oscillations in the whole shock spectrum of the test (the lower level of scale = 0, the strongest blow – the upper level of scale = 7.0 divisions) at the positive and negative temperature of tests [14].

The damping properties of the pack of plates without lubricant compositions are at the low level δ=0.43, under almost any conditions.

As a result of the research of the plate dampers the effective silicone fluids of the type PMS, produced by the domestic industry are selected, and the optimal reliefs of the plate surfaces are selected, and the methods of analysis, design, testing and assessment tools of the damping and load capacity are developed.

Studies [2, 12 and 15] showed a high level of the absorptive capacity of the plate dampers, in which elastomeric fluids are applied as a lubricating layer. The most effective compositions of the damping fluid are given in Table 1. Fig. 9 shows the design of the plate elastomeric shock-absorber of the vertical suspension of a railway car.

In practical terms, the achievement of the use of the proposed plate elastomeric shock-absorbers of a high degree of the vibration resistance of various units with their small dimensions is most significant [2, 3, 7, 8 and 16].

Table 1. The average value of the logarithmic decrement of damping when tested the plate shock-absorber

The temperature of the absorber	-10 °C		The average value δ when -10 °C	+ 20 °C		The average value δ when +20 °C
Type of tests of shock-absorber	The average value δ at the static load on the shock-absorber, kg*			The average value δ at the static load on the shock-absorber, kg*		
	171	342		171	342	
Without lubrication	0,40	0,50	0,45	0,50	0,35	0,43
PMS500	1,40	1,10	1,25	1,35	1,10	1,23
PMS60000	1,15	0,70	0,93	1,15	0,95	1,05
Industrial I-20	1,20	0,80	1,00	1,00	0,50	0,75
Rubber 18x27x110 mm - 2 pcs.	1,25	0,80	1,03	1,10	0,18	0,64
With multilayer grease (2 components):						
PMS500+I-20	1,50	0,75	1,13	1,40	0,95	1,18
PMS60000+I-20	1,20	0,50	0,85	0,70	0,85	0,78
PMS60000+ PMS500	0,90	1,20	1,05	1,20	1,65	1,43

* - when the strength of the shock-absorber is from 2.0 to 5.0 divisions.

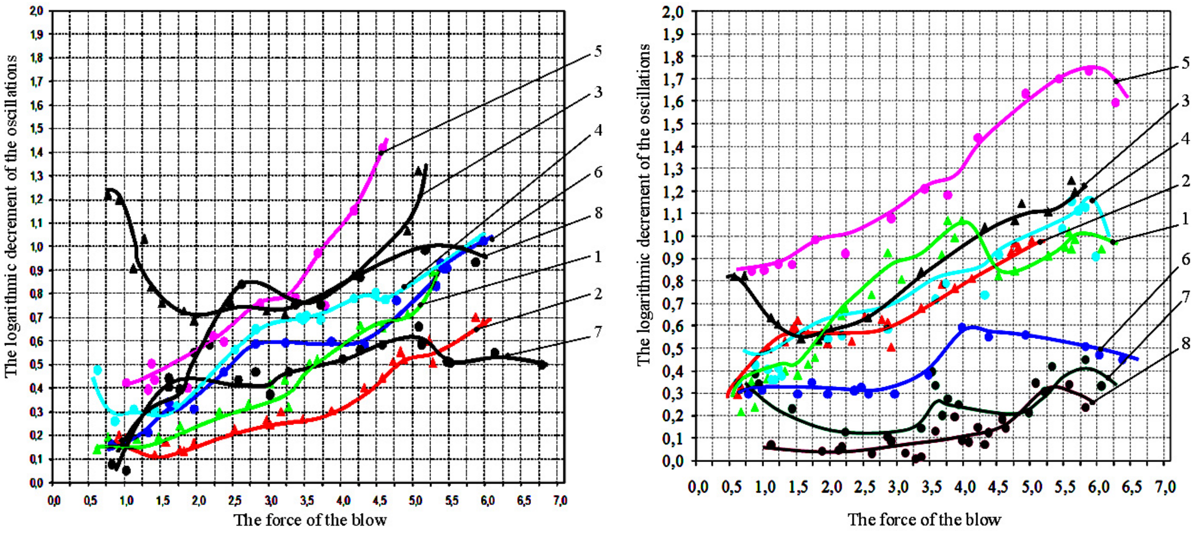


Fig. 8. The dependence of the logarithmic decrement of the oscillations of a plate shock-absorber on the force of the blow when the static load is 342 kg and the temperature: a - is -10°C…-15 °C; b - is +20 °C; 1 - PMS60000; 2 - PMS60000 + I-20; 3 - PMS500; 4 - PMS500 + I-20; 5 - PMS60000 + PMS500; 6 - I-20; 7 - without of oil; 8 - rubber.

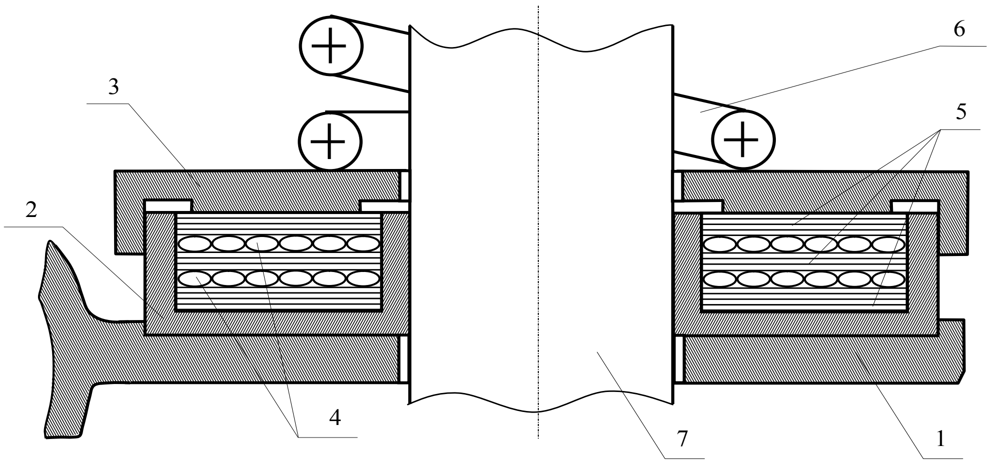


Fig. 9. The device work unit of the plate elastomeric shock-absorber of vertical suspension railway car: 1 - lug axle boxes; 2 - body; 3 - top cover; 4 - wires packages of quasi-closed rings; 5 - packs of corrugated washers; 6 - spring axle suspension; 7 - tail; 8 - relief of the surface of the wafer.

4. Analysis of the results

The tests, studies and analysis of the system showed that described in the article the development of the use of vane dampers allow to significantly improve dynamic stability of mechanical systems.

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